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Informal Urban Development in the Greater Buenos Aires Area: A Quantitative-Spatial Assessment Based On Households' Physical Features Using GIS and Principal Component Analysis

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Abstract

Informal urban development (IUD) is a key driver of urbanization in Latin America, which is challenging urban planning and governance. According to the last national census of 2010, in Argentina more than a fifth of households of the Greater Buenos Aires Area (GBA) live in inadequate housing conditions, in the most densely populated urban agglomeration in the country. The situation has worsened compared to the years 1991 and 2001. This IUD lacks recommended minimum housing standards and is thus outside urban planning regulations. An updated assessment that quantifies and characterizes existing levels of IUD is needed to support policy measures to improve households living conditions. This paper analyses the spatial distribution of IUD in the GBA on the basis of the census data 2010. To quantify levels of IUD, households' housing physical features (material and infrastructural) were analysed using principal component analysis (PCA).

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The aim was to ascertain the importance of different housing physical features in accounting for IUD variability. For this purpose, a PCA was performed at two geographical scales. Firstly, at the provincial level to analyse the behaviour of IUD in the GBA in a wider geographic context; and secondly, at the metropolitan scale to evaluate the robustness of the first analysis. In a second step such IUD levels were mapped and analysed to assess their spatial distribution and identify the areas with higher levels and concentrations of IUD. The results show that a high variability of IUD can be explained by one principal component, being Housing construction and Housing material the most important variables in accounting for discrepancies in IUD variability. Furthermore, high levels of IUD are spatially concentrated in those census tracks closer to the fringe of the GBA.

1. Introduction

Informal urban development (IUD) is a widespread and long-standing phenomenon in Latin America. During the last decades, despite the proliferation of land tenure regularization and settlement-upgrading programs, IUD still constitutes the predominant mode of access to urban land and housing for lower income households in many Latin American countries [1, 2]. In fact, 24 per cent of the urban population currently lives in informal settlements in the Latin America and Caribbean region [3]. Furthermore, it is estimated that 70 per cent of new housing production in the region is developed in informal ways, thus lacking from recommended minimum housing standards and outside urban planning regulations [4].

There are significant differences among Latin American countries in terms of their urban population living in informal areas [5, 6]. In Argentina, according to a report published by the UN Statistics Division [7], a 26% of its urban population lived in slums in the year 2005. With such large amount of IUD, Argentina is among the countries in Latin America and the Caribbean with a higher prevalence of IUD in large cities and metropolitan areas. In the case of the Greater Buenos Aires Area (GBA), the urban agglomeration concentrating 32% of the country's population, more than a fifth of households live in inadequate housing conditions, according to the last national census of 2010. The situation has worsened compared to the years 1991 and 2001, consolidating an increase in IUD. A relevant part of the area has developed in informal ways, lacking recommended minimum housing standards and outside urban planning regulations. An updated assessment that quantifies and characterizes existing levels of informality is needed, to support effective policy measures to improve households living conditions. As informality is a complex and multi-dimensional phenomenon, quantifying its magnitude and spatial distribution remains an important challenge on the Latin American research agenda [8]. This paper aims at analyzing the spatial distribution and levels of IUD in the GBA, assessing the importance of different housing physical features in accounting for discrepancies in IUD variability on the basis of the data provided by the census 2010.

2. Measuring informal urban development

Quantifying IUD is critical for designing and assessing effective public policies. The international literature generally assumes that IUD takes two main dimensions that usually overlap and are interrelated [5,9,10].

1) From a legal point of view: the household's illegal land tenure status, where the dwelling is located, or of the dwelling itself.

2) A material and infrastructural level: a housing unit constructed of non-durable materials, lacking of construction finishes and/or lacking of essential public services such as drinking water or sewerage.

A third dimension normally associated with IUD relates to the dwelling and plot compliance with urban norms and regulations. This last meaning can lead to operational definitions of informality that are quite fuzzy or misleading when seeking objective quantifiable measures of informal urban development. For instance, when evaluating proxies for informality sometimes the failure to comply with urban regulations is included. However in the Latin American context such situation it is not exclusively limited to low-income conditions, but would also include irregular or illegal high-income buildings or housing where forbidden materials were used [11].

In conclusion, this legal dimension of informality does not say anything about the quality of the material living conditions of the low –income population, which is certainly where the focus should be placed.

As IUD is a multidimensional phenomenon, concerning legal, physical and socio-economic features, establishing an operational definition to assess its magnitude or evaluate policy performance implies profound methodological complexities. On the one hand, not only do proxies for informality differ across countries and urban/rural areas but also its magnitude can vary considerably depending on the variables chosen to measure it. This lack of consensus on

variables and proxies to measure IUD has negatively affected attempts to compare levels of informality and policy performance across countries or cities in Latin America [11].Even within the same country problems of definition and measurement of IUD can be found due to a deficiency of appropriate or comparable data, lack of consensus on the appropriate proxies to measure informality, or even different urban development "informal" responses following changing climatic conditions across the country. On the other hand, informality measures may change considerably even within a proxy indicator [11].For instance, the percentage of households without access to sewer and water systems can vary depending on how the supply is classified. If it is defined strictly as a connection to the public network, or more broadly as a connection to, either the public network or alternative supply systems then the percentage would be different. Similar discrepancies are found for the proxy indicators that measure other dimensions of informality like the legal one [11].

Furthermore, in Latin America and the Caribbean region the informal access to land and housing has been characterized as an essentially gradual or progressive process [6,12,13]. The impossibility of accessing a mortgage loan, a housing programme from the government or adequate housing in the formal market leads many poor families to build their dwellings step by step, whether they have had access to the plot through a legal real estate transaction, through a family transfer, through a permit or by direct occupation. In the case of lower income households, housing investment depends essentially on the availability of income, therefore it is usually done at a slow pace with gradual purchases of materials, by self-building and outsourcing of skilled labour in different periods of time. The early stages comprise the building of a basic structure to which rooms, bathroom and kitchen are added little by little, in an upgrading process that might take years, and where temporary materials are gradually replaced by more durable ones. Depending on the level of organization of the population and/or the capacity to put pressure on local governments, the access to basic public services such as water and sanitation may finally be provided and land tenure may also be formalized over time. In summary, from a methodological point of view, this progressive housing process hampers the possibility of making comparisons and assessing improvements across space and over time. To characterize and measure levels of IUD, households' housing physical features (material and infrastructural) were analysed. A secondary aim was to quantify the importance of different physical deficiencies in IUD variability in the GBA.

3. Material and Method

3.1. Study area

The study is focused on the Greater Buenos Aires Area (GBA), an urban agglomeration made up of the Autonomous City of Buenos Aires (ACBA) and the surrounding twenty four municipal jurisdictions (Fig. 1c).The GBA is located in one of Argentina's 23 provinces, the Province of Buenos Aires, which is the largest and most populous in the country. The GBA concentrates about 32% of the total population of Argentina, making it the most densely populated urban agglomeration in the country.

3.2. Statistical analysis

The data set for the analysis is from the 2010 National Census of Population, Households, and Housing, conducted by the Argentine National Institute of Statistics and Censuses [14]. The spatial distribution of IUD in GBA was assessed on the basis of an analysis performed at the lowest available spatial unit for aggregated census data, the so called "radio censal", census track in this paper. It comprises around 300 housing dwellings. Households' physical features, including material and infrastructural dimensions of IUD**,** were analysed in order to characterize, measure and map IUD, as well as ascertain the respective weight of such dimensions within the inner structure of overall urban informality. For this purpose, a principal component analysis (PCA) was performed at two geographical scales. Firstly, at Buenos Aires Province level (Fig. 1b) to ascertain the degree of IUD in GBA in the context of a wider geographical scale. Secondly, a PCA was done at Buenos Aires Metropolitan Region (BAMR) level to give a more accurate picture of IUD in the GBA and ascertain the robustness of the first analysis at a smaller scale. The GBA is comprised in the BAMR, which is made up of a total of 40 municipalities that surround the Autonomous City of Buenos Aires (ACBA).

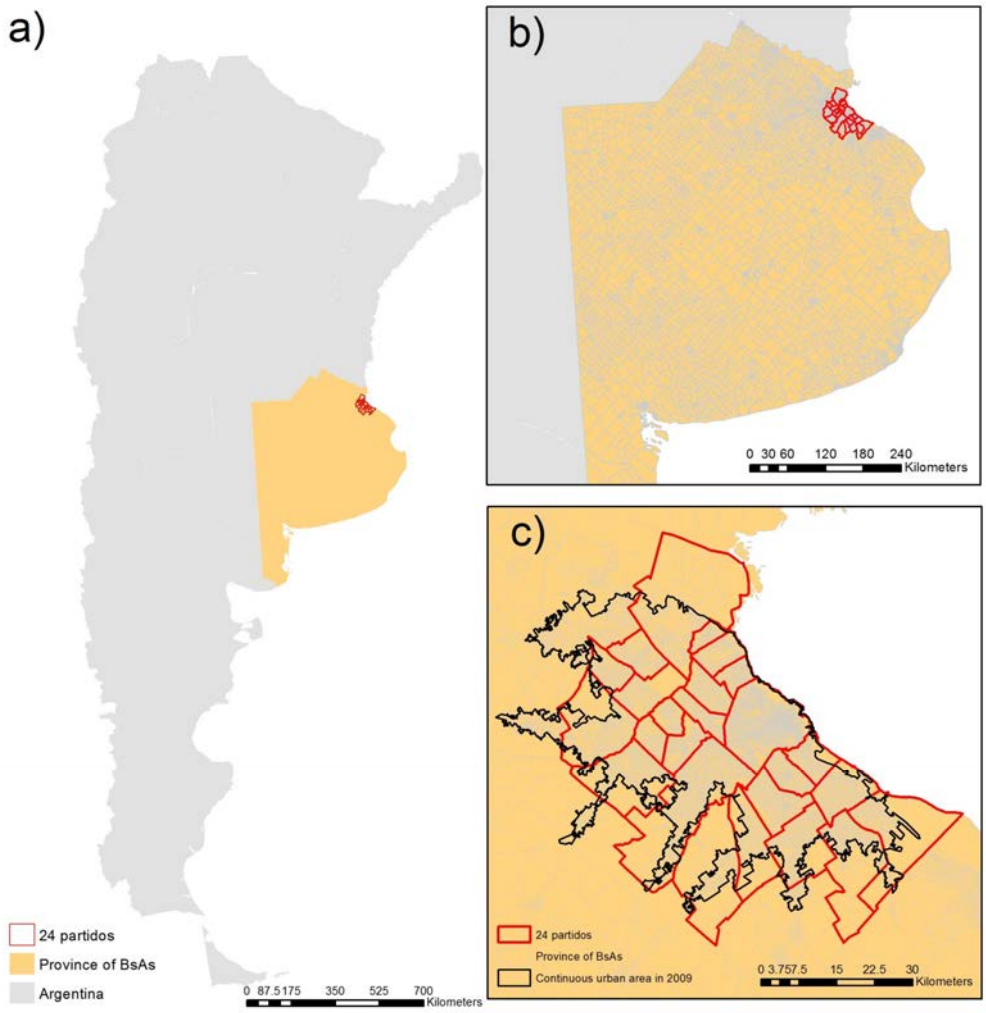

Figure 1. Location of the study area within the country and the Province. In caption
c) the 24 municipal jurisdictions (*partidos)* are shown, the continuous urban area as of 2009 is taken from [8].

PCA is a statistical procedure to reduce the original variables into a smaller number of principal components that will account for most of the variance in the observed variables. PCA reduces the complexity of the variables avoiding co-linearity. It is expected a high level of correlation between variables: the informality measured using physical variables will tend to concentrate in specific households depicting several features of informality at the same time, rather than larger amounts of households having only one feature of informality. PCA accounts for such co-linearity. In a second stage, IUD levels were mapped and analysed using GIS tools to assess and understand their spatial distribution.

For the purpose of characterizing the physical dimension of informality seven variables were selected (Table 1). IUD is normally associated with a lack of durability in housing [9] and/or a lack of public services [10]. Thus, based on these criteria variables were chosen to account for different specificities of informality as well as ascertain different levels of spatial concentration:

1) Infrastructural informality (*no piped water* and *no WC*): understood as a lack of access to basic public services.
2) Material informality (*floor* and *roof* building materials and *house type*): understood as a precarious dwelling made of non-durable materials or lacking of some basic construction finishes.

From those seven selected variables, only specific categories were used as informality proxies. In selecting the categories within the variables special consideration was taken to avoid confusion between typical features of IUD and rural settlements. Table 1 lists all the categories used in each variable.

Table 1. Selected proxies for material informality and corresponding categories.

	Variables	Used categories
1	Piped Water	1) Outside the plot
2	No Wc	1) Pit latrine; 2) Pit; 3) Without toilet
3	Floor	1) Bare earth flooring or loose brick
4	Roof	1) Sheet metal (no cover); 2) Fibber cement or plastic sheet; 3) Cardboard sheet;4) Cane, palm, table or straw with or without mud
5	House type	1) Shanty; 2) Hovel; 3) Building not habilitated as dwelling
6	Housing construction quality	1) Insufficient [i]
7	Housing material quality	1) Quality III[ii]; 2) Quality IV[iii]

[i] Comprises dwellings that do not have adequate insulation materials or that have tin or fibber cement roof. It also includes housing units that do not have piped water inside the dwelling and toilet with water discharge.
[ii] Comprises dwellings where the roof and floor are made of low resistant and non-durable materials.
[iii] Comprises dwellings where the roof and floor are made of low-quality materials.

3.3. Spatial analysis

To ascertain the spatial distribution of IUD a cluster analysis using the Local Moran's I statistic [15] of spatial association was used. This test provides a set of weighted features, identifies statistically significant hot spots, cold spots, and spatial outliers. Spatial clusters of features with attribute values similar in magnitude are identified.

4. Results and discussions

4.1. The Principal Component Analysis at the provincial level

The universe of analysis consists of 23,132 census tracks belonging to the Buenos Aires Province, of which 19,577 census tracks are located in the Province of Buenos Aires and 3,555 in the Autonomous City of Buenos Aires. The seven selected variables in Table 1 were subjected to a principal component analysis (PCA) performed on a provincial scale. Only the first principal component (PC1) displayed an *eigenvalue* greater than 1, and therefore filling the Kaisers rule to be retained. The high value obtained by the first component (4,923) suggested that only the first component was meaningful. Therefore, only the first component was retained for rotation. The remaining six *eigenvalues* displayed values smaller than 1. The p-value resulting from the Bartlett's sphericity test was 0.0001, thus the null hypothesis was neglected.

The PC1 accounted for 70.3% of the total variability of the data set, being a strong component to explain overall IUD. With only one principal component explaining a high percentage of the data variability, the structure of factor loadings is clear and simple. Selected variables and corresponding factor loadings are presented in Table 2.

Housing construction (0,726) and *housing material* (0,732) are the variables with higher weight within the retained PC (Table 2). The second variable displaying a relatively high value within the PC1 was *No WC* (0.391), thus the most relevant infrastructure feature when accounting for variability in IUD.

Table 2. Eigenvalues and rotated factor pattern from Principal Component Analysis

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigenvalue	4.92	0.96	0.38	0.31	0.20	0.16	0.06
Variability (%)	70.33	13.73	5.41	4.45	2.88	2.34	0.86
Cumulative %	70.33	84.06	89.48	93.92	96.80	99.14	100.00
Factor loadings after Varimax rotation	PC1	PC2	PC3	PC4	PC5	PC6	PC7
No piped	0.221	0.532*	0.131	0.217	0.166	0.759	0.002
No WC	0.391	0.188	0.340	0.209	0.793	0.153	-0.005
Floor	0.184	0.890*	0.136	0.243	0.151	0.270	0.000
Roof	0.277	0.127	0.900	0.167	0.243	0.098	0.006
House Type	0.337	0.338	0.223	0.797	0.214	0.205	0.001
Housing construction	0.726	0.216	0.297	0.308	0.388	0.243	0.182
Housing material	0.732	0.233	0.406	0.303	0.317	0.152	-0.173

4.2 The spatial distribution of informal urban development at the provincial level

The spatial distribution of higher IUD values is very clear, being concentrated around the peri-urban ring of the GBA and around the edge of the continuous urban area as of 2009 (Fig. 2a). The cluster analysis confirms this spatial trend (Fig. 2b), where higher values (HH) are mostly located at the peri-urban edge of the GBA (Fig. 1b). In the Province of Buenos Aires there are 2,097 total census tracks with IUD values greater than the average plus one standard deviation (0.673) of which 1,940 (92.5%) are located within the limits of the continuous urban area of the ACBA. Higher levels of IUD tend to concentrate more intensively in those areas towards the west and south-west of the urban agglomeration close to the edge of the continuous urban fabric (Fig. 2c).

4.3 The Principal Component Analysis at the metropolitan level

The results obtained at the province level were corroborated by a second PCA performed over Buenos Aires Metropolitan Region (BAMR), which comprises the ACBA and 40 surrounding municipalities. This analysis included 15,010 census tracks in total. Only the first component displayed an *eigenvalue* greater than one (4.816), explaining 68.8% of the total variability of IUD in the data set (Table 3). The structure of factor loadings after varimax rotation is strongly similar to the one obtained at the province level, confirming the high weight of the variables *Housing construction* and *Housing material*. In this smaller sample 2,176 census tracks have a value higher than the average plus one standard deviation, confirming both, the statistical weight and the spatial distribution of the results obtained at the province level. As in the previous PCA, *No WC* was the following variable that had a higher weight than the other ones considered, remaining as the most outstanding material feature that accounts for IUD variability.

Table 3. Eigenvalues and rotated factor pattern from Principal Component Analysis.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigenvalue	4.816	0.894	0.354	0.339	0.276	0.247	0.075
Variability (%)	68.802	12.768	5.056	4.838	3.938	3.522	1.076
Cumulative %	68.802	81.569	86.625	91.464	95.401	98.924	100.000
Factor loadings after Varimax rotation	PC1	PC2	PC3	PC4	PC5	PC6	PC7
No piped	0.199	0.309	0.139	0.883	0.213	0.146	-0.001
No WC	0.390	0.154	0.318	0.171	0.184	0.812	0.004
Floor	0.223	0.866	0.129	0.328	0.241	0.138	0.001
Roof	0.314	0.126	0.872	0.142	0.191	0.263	-0.004
House Type	0.314	0.314	0.244	0.288	0.787	0.201	0.001
Housing construction	0.778	0.220	0.258	0.257	0.246	0.341	-0.192
Housing material	0.771	0.228	0.374	0.163	0.247	0.291	0.203

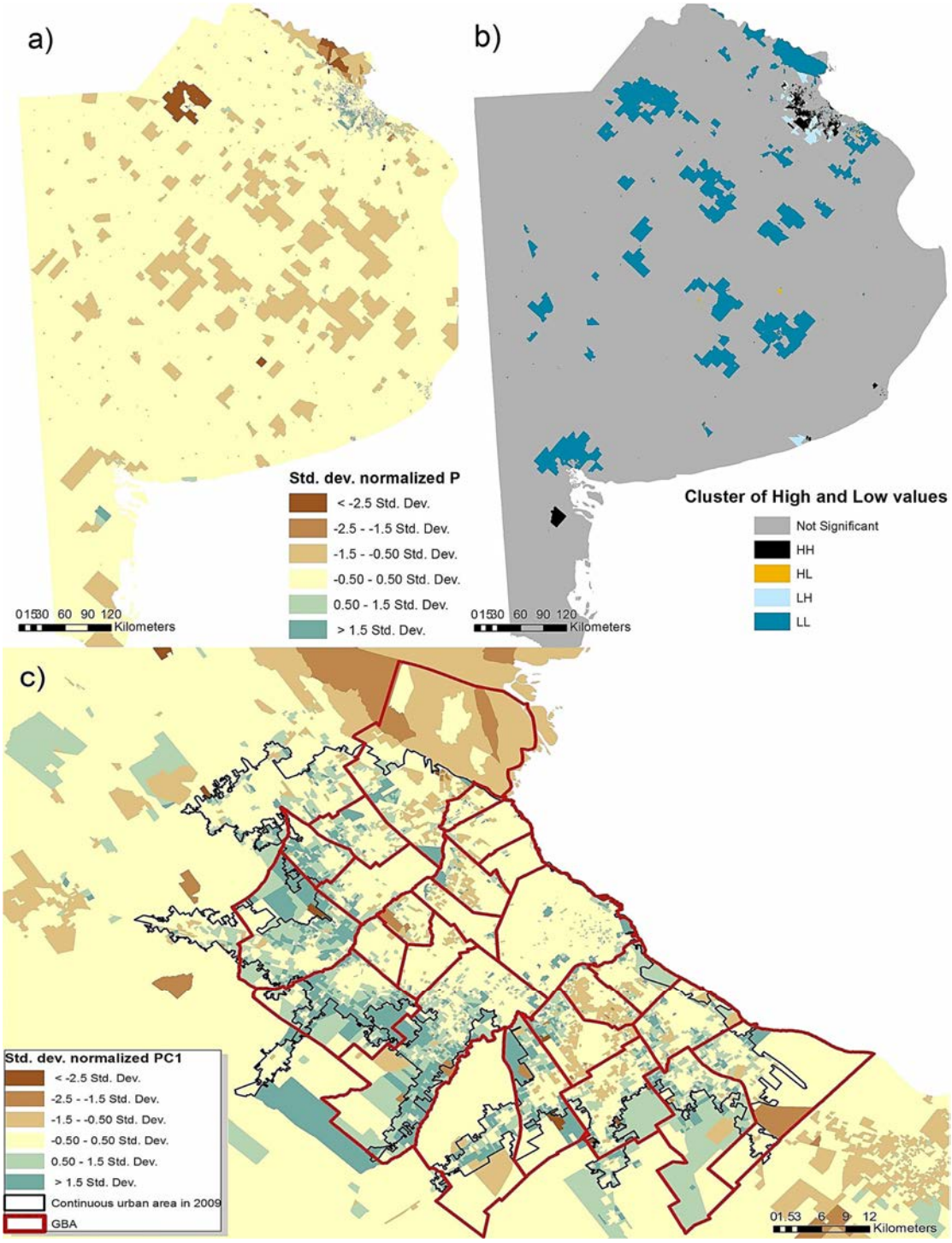

Figure. 2. Standard deviation of normalized values of PC1 for the Province of Buenos Aires (a, c). Caption (b) shows the cluster Moran I analysis for the entire Province, where HH (black) high values, LL (blue) low values. All high values cluster around the GBA.

4.4 The spatial distribution of informal urban development at the metropolitan level

The spatial distribution of higher IUD values over Buenos Aires Metropolitan Region (BAMR) clearly shows that the census blocks close to the fringe of the GBA concentrate the most precarious situations in terms of access to basic services and housing building materials (Fig.3). Over a total of 2,176 census tracks with IUD values greater than the average plus one standard deviation (0.5404), 1,977 (90.8%) are located within the limits of the GBA.

The municipalities of the GBA are divided in a series of successive rings, located according to their proximity to the ACBA. This classification implies certain homogeneity within each of them, resulting of the different periods in which they developed as the agglomeration grew. A 23% of the GBA is made up of census tracks with IUD values greater than the average plus one standard deviation.

Of the total 24 municipalities that make up the GBA, five of them have 40 per cent or more of their surface comprising census tracks with IUD values greater than the average plus one standard deviation (Merlo, San Miguel, the west area of La Matanza, José C. Paz and Moreno). These municipalities are located in the second ring that surrounds the ACBA. However, not all of the municipalities with large part of their surfaces with high IUD levels are those more distant from the capital city. For instance, three municipalities located in the first ring that surrounds the city present values over 22% and that reach a maximum of 37% (Lomas de Zamora, Avellaneda and Lanús). These municipalities, located in the south of the ACBA and separated from it by the Riachuelo River, are situated in an area where social and urban inequalities have been persistent for decades. With the exception of a municipality located to the west of the city in the first ring (Ituzaingo), the municipalities that present lower levels of IUD are located in the second ring to the north of the ACBA, characterized mainly by their neighbourhoods and gated communities for the upper-middle and upper classes. (Tigre, San Isidro, Vicente López).

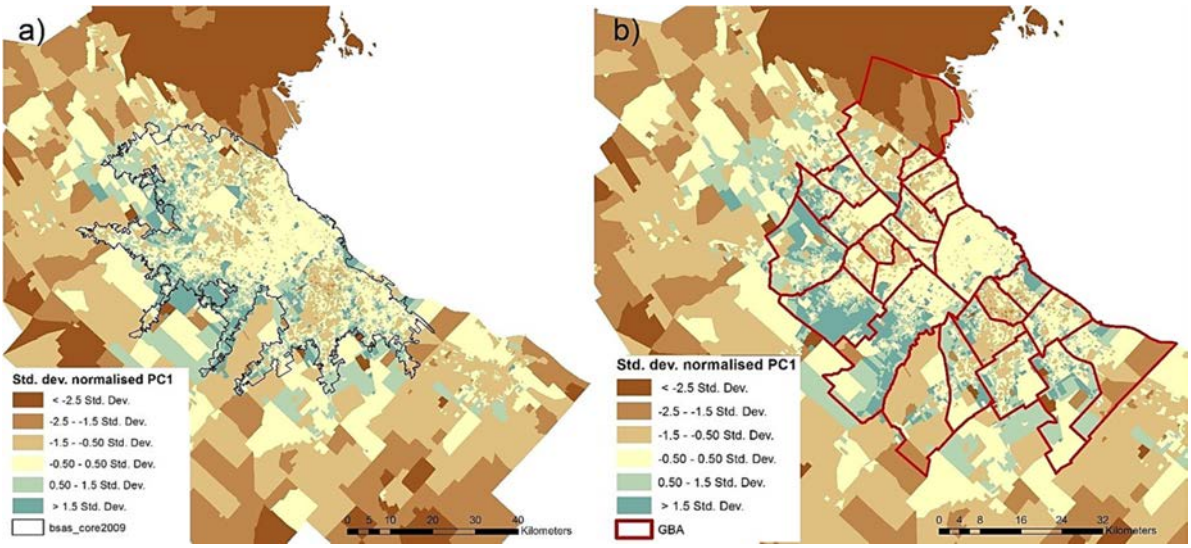

Figure 3. Standard deviation of normalized values of PC1 for the Buenos Aires Metropolitan Region. Continuous urban area and BMA are shown in caption a) and b) respectively.

5. Conclusions

The results of the PCA analyses performed at two different geographical scales (provincial and metropolitan) show that IUD follows a well-defined and specific spatial pattern. The areas with higher IUD levels tend to concentrate significantly in the census blocks close to the fringe of the GBA. For instance, those municipalities with very high levels of IUD are bordering the second ring limit of the GBA. Furthermore, according to the analyses, this specific structural IUD trend is not sensible to changes in scale: the PCA performed for the metropolitan region corroborated the results obtained at the province level.

The variability of IUD can be explained by one principal component. The variables *Housing construction* and *Housing Material* accounted as the most important features when explaining variability in the data set. This means that the physical dimension of informality is very relevant when accounting for the differences in households' access to urban services and availability of adequate housing in the analysed area.

The spatial distribution of census tracks with high values of IUD clearly shows that the most vulnerable situations are found around the edge of the GBA. This constitutes a clear orientation for developing urban measures and public policies that improve households living conditions in this area. According to the results, in designing settlement upgrading programmes special attention must be given to improving physical housing conditions as this feature revealed as a very important one when accounting for IUD variability.

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